

2 Effects of Water and Fertilizer Management on Growth and Development of *Rubus chingii*

2.1 Effects of water supply on vegetative growth and root development of *Rubus chingii*

Rubus chingii is a woody perennial medicinal and edible shrub whose field productivity depends on stable vegetative growth and effective root water uptake (He et al., 2023). Although direct irrigation studies in *R. chingii* are still limited, evidence from raspberry and other perennial fruit crops shows that water supply strongly regulates canopy expansion, branch growth, plant water status, and ultimately the root-shoot balance (Li et al., 2024; Venig and Teuşdea, 2026). In red raspberry, irrigation level significantly changed yield, fruit number, plant water status, and water productivity, and irrigation at 75% ET_c produced the highest yield while saving 20~28% of water relative to heavier irrigation, indicating that moderate water supply can outperform excessive irrigation. Likewise, pulse drip irrigation in raspberry improved soil water availability and increased later-season production, while also increasing canopy cover and cane diameter in one or both years, showing that irrigation pattern as well as irrigation amount can affect vegetative vigor (Carroll et al., 2024).

Water deficit generally suppresses aboveground growth first, but moderate deficit can redirect assimilates toward the root system and improve water-use efficiency. In jujube, mild deficit irrigation reduced plant height growth and leaf area index, yet helped optimize source-sink relations and improved water-use efficiency, whereas severe deficit caused persistent physiological damage and stronger growth inhibition (Qiang et al., 2025). Pear studies further show that roots are highly sensitive to local water and nutrient conditions, and suitable water-fertilizer treatments increased root area and root density in the 0~60 cm soil layer while sustaining a higher leaf area index (Li et al., 2024). In apricot nursery plants, moderate irrigation maintained higher soil moisture and produced vegetative growth comparable to higher irrigation depths, again suggesting that growth benefits plateau once water supply exceeds plant demand (Venig and Teuşdea, 2026). For *R. chingii*, these findings support the expectation that insufficient water will restrict shoot extension, leaf development, and root activity, while a moderate and well-timed water supply should favor coordinated vegetative growth and a more efficient root system.

2.2 Effects of nitrogen, phosphorus, and potassium supply on plant growth and biomass accumulation

Nitrogen, phosphorus, and potassium are the primary macronutrients controlling plant growth, biomass formation, and nutrient metabolism, and their effects are especially important in medicinal plants because biomass production and active compound accumulation often respond differently to fertilization intensity (Fang et al., 2024; Chrysargyris and Tzortzakis, 2025a). In *Ophiopogon japonicus*, nitrogen source, P+K fertilization, and micronutrient supply all significantly affected agronomic traits and biomass production; P+K promoted plant height and fibrous root growth, and all three fertilization factors significantly affected tuber biomass, the main determinant of medicinal yield (Cai et al., 2025). This pattern is consistent with the broader evidence that balanced NPK supply, rather than single-nutrient maximization, is required to regulate root development, biomass accumulation, and whole-plant health. A global meta-analysis further found that aboveground biomass increased with N, P, and K additions individually, but increased more strongly with combined nutrient additions, especially NP and NPK treatments, supporting widespread nutrient co-limitation of plant growth.

The response to N, P, and K supply is not linear, and moderate or balanced rates often outperform deficiency and excess. In *Sideritis cypria*, an intermediate NPK scheme increased phenols, flavonoids, and antioxidant activity, whereas low nitrogen reduced fresh weight and chlorophyll, and very high potassium induced oxidative stress (Chrysargyris and Tzortzakis, 2025a). In *Origanum dubium*, intermediate NPK levels improved tissue potassium status, low potassium reduced biomass and increased oxidative stress, and higher nitrogen increased N accumulation and flavonoids but altered essential-oil composition (Chrysargyris and Tzortzakis, 2025b). Field evidence from *Vitex negundo* also shows that phosphorus supply can substantially increase biomass and essential-oil yield, with 200 kg P/ha producing the highest biomass and bioactive ingredient content (Peng and Ng, 2022). Because *R. chingii* fruit quality depends on flavonoids, phenolics, terpenoids, and related metabolites, balanced N, P, and K nutrition likely supports not only shoot and root biomass accumulation but also the material basis for later fruit yield and medicinal quality formation (Figure 1) (Yu et al., 2019; He et al., 2023; Wu et al., 2024).